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(54) **LIQUID CRYSTAL DEVICE AND ELECTRONIC APPARATUS**

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G02F 1/1335 (2006.01)

(52) **U.S. Cl.** 349/114; 349/113

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349/106, 110, 113, 114, 117, 141, 155
See application file for complete search history.

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(57) **ABSTRACT**

A liquid crystal device includes a pair of substrates, a liquid crystal layer provided between the substrates, and a plurality of sub-pixels each having a transmissive display region and a reflective display region. One of the substrates includes switching elements corresponding to the sub-pixels, lines connected to the switching elements, and an insulating film provided on the switching elements and the lines. The insulating film includes first recesses provided in the transmissive display regions, and second recesses provided along boundaries between the adjoining sub-pixels. At least a part of the insulating film other than the first and second recesses planarly overlaps with the reflective display regions. The thickness of the liquid crystal layer is smaller in the reflective display regions than in the transmissive display regions having the first recesses. The depth of the second recesses is smaller than the depth of the first recesses.

12 Claims, 6 Drawing Sheets

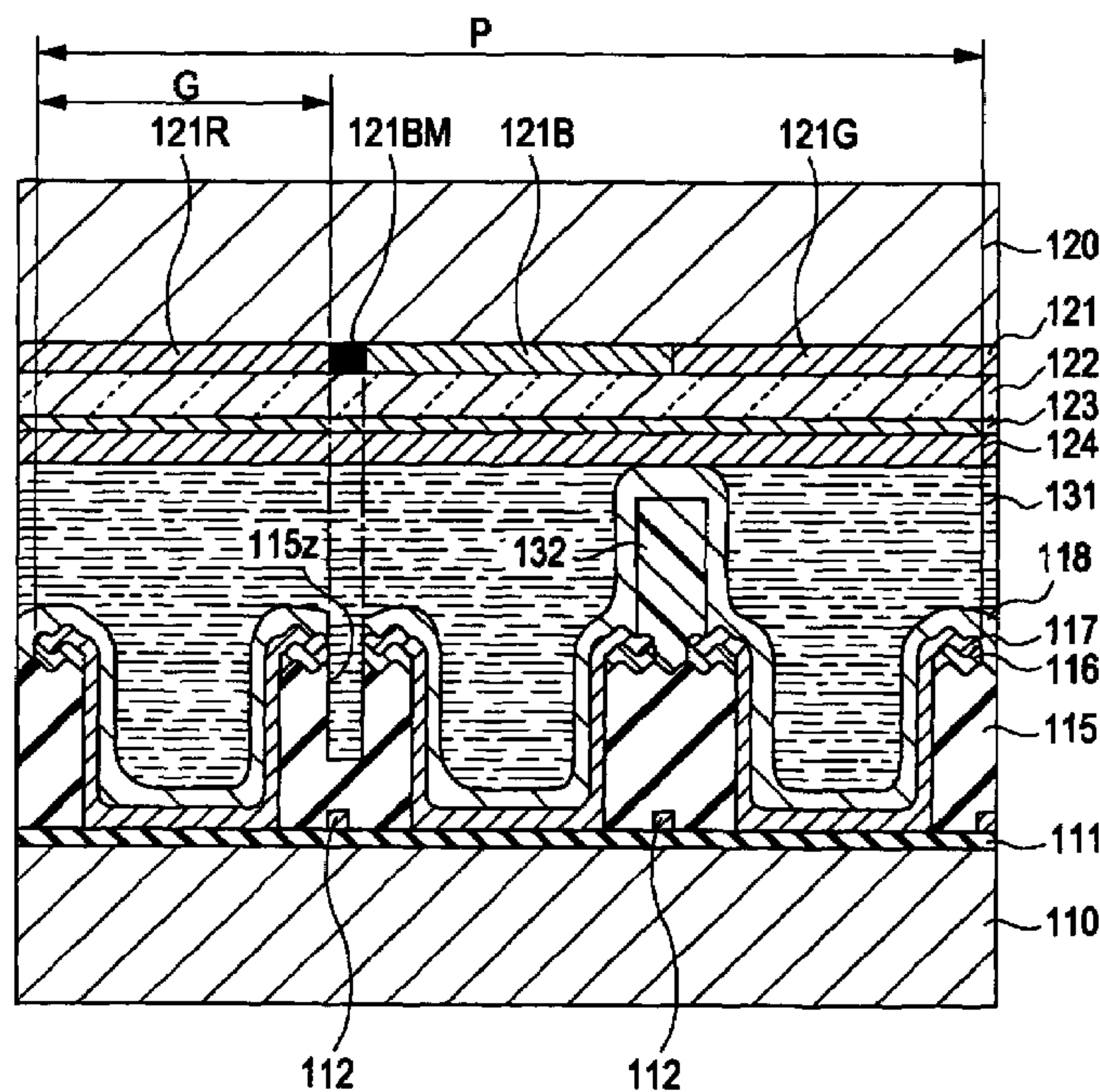


FIG. 1

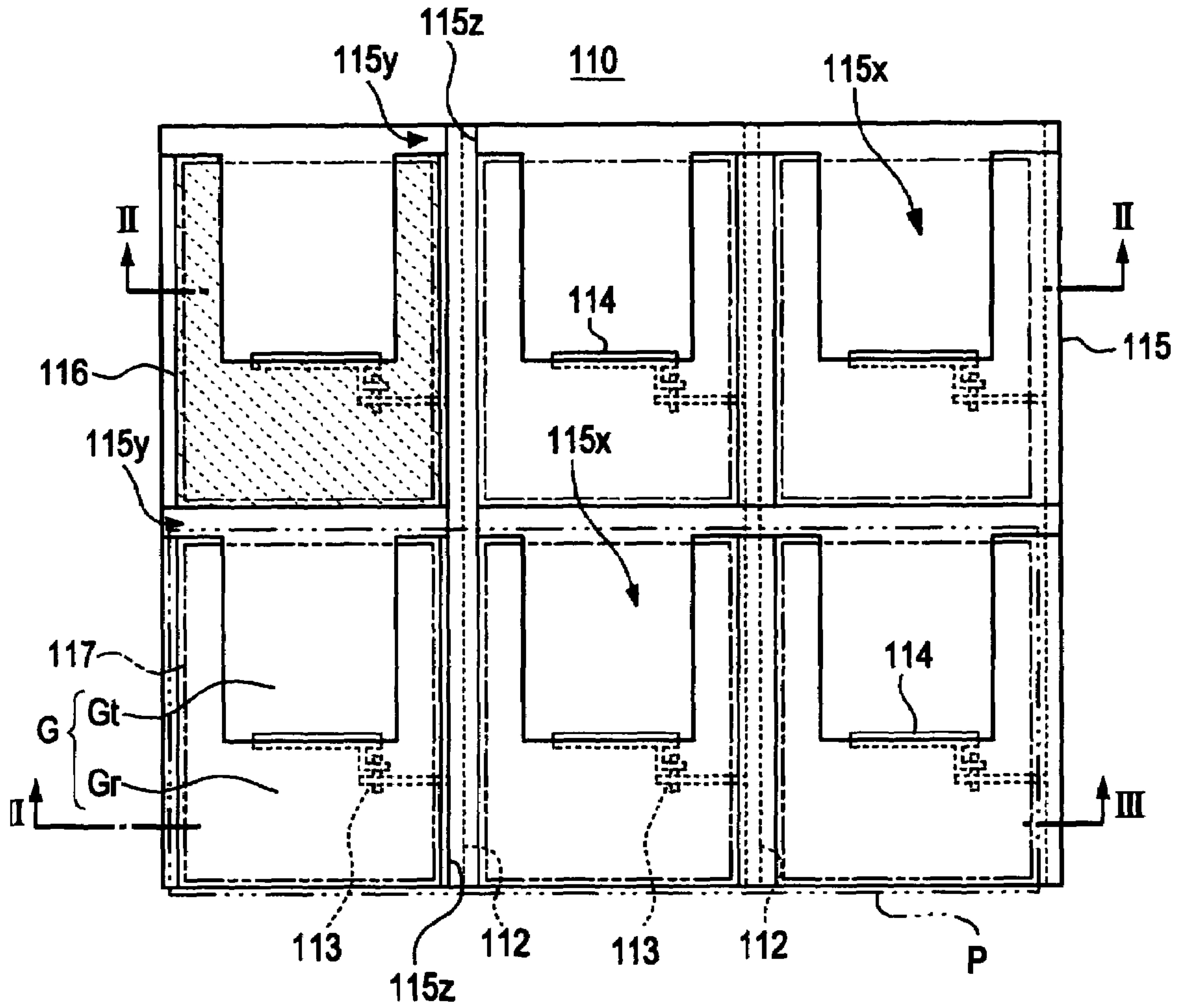


FIG. 2

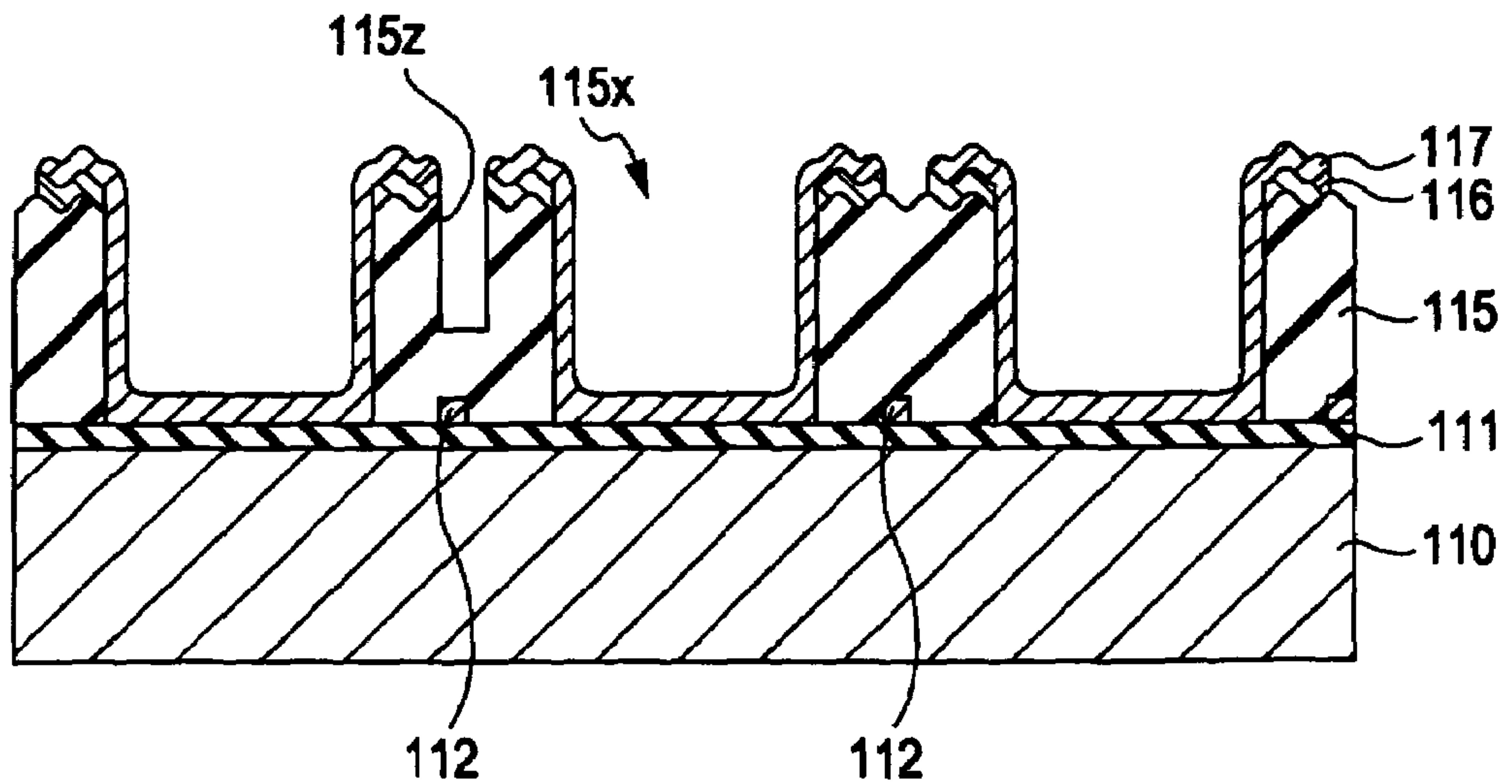


FIG. 3

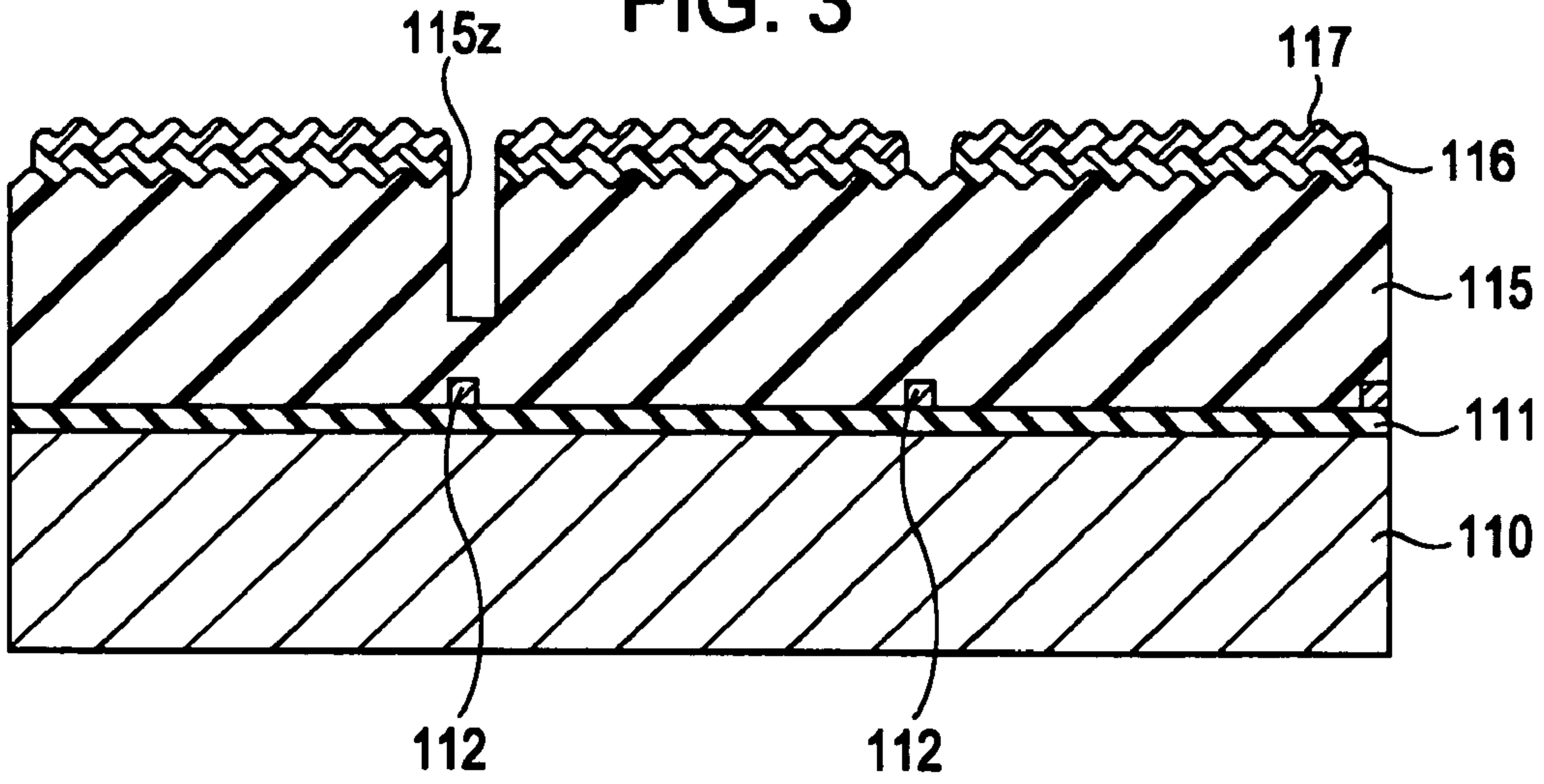


FIG. 4

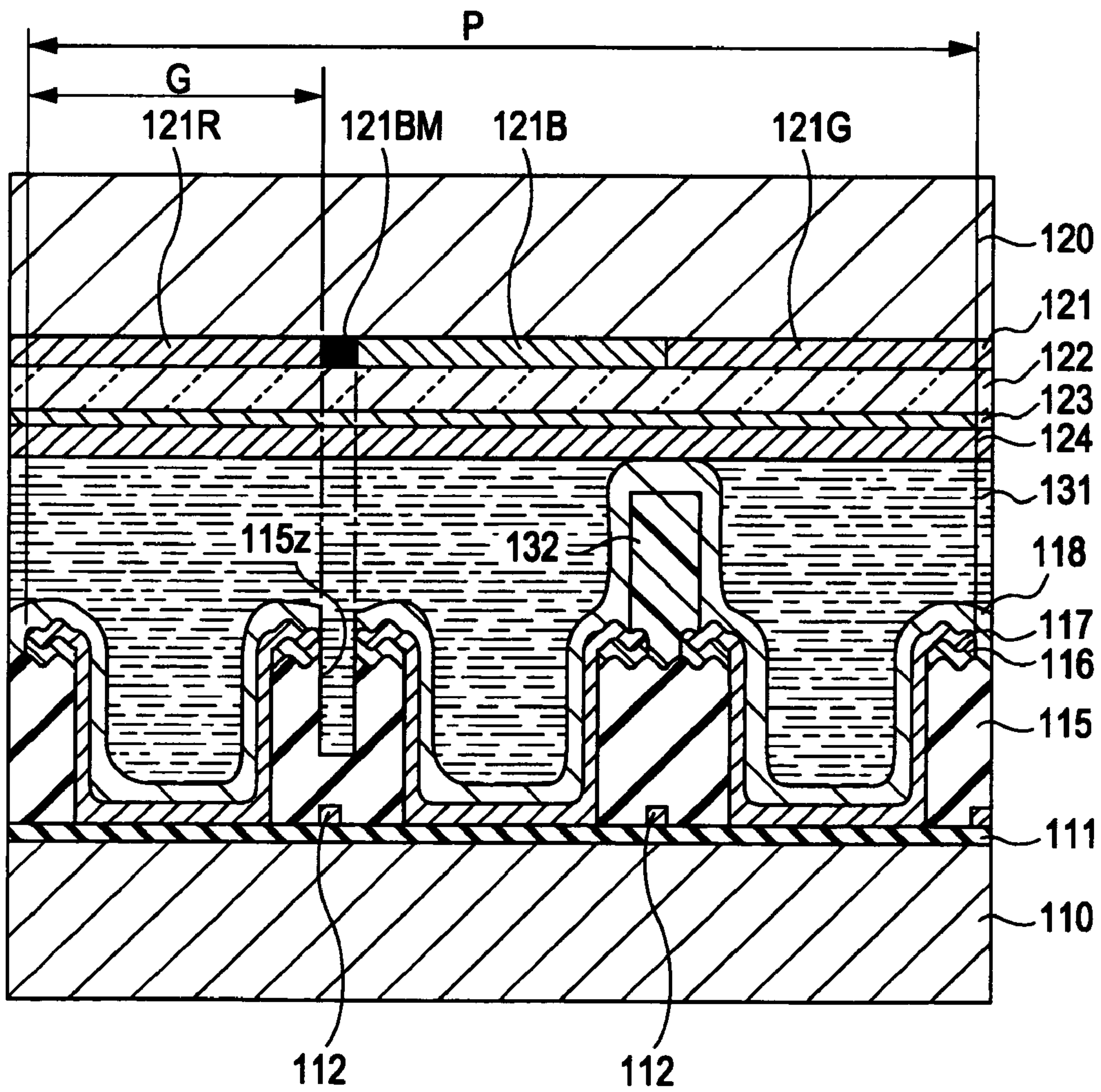


FIG. 5

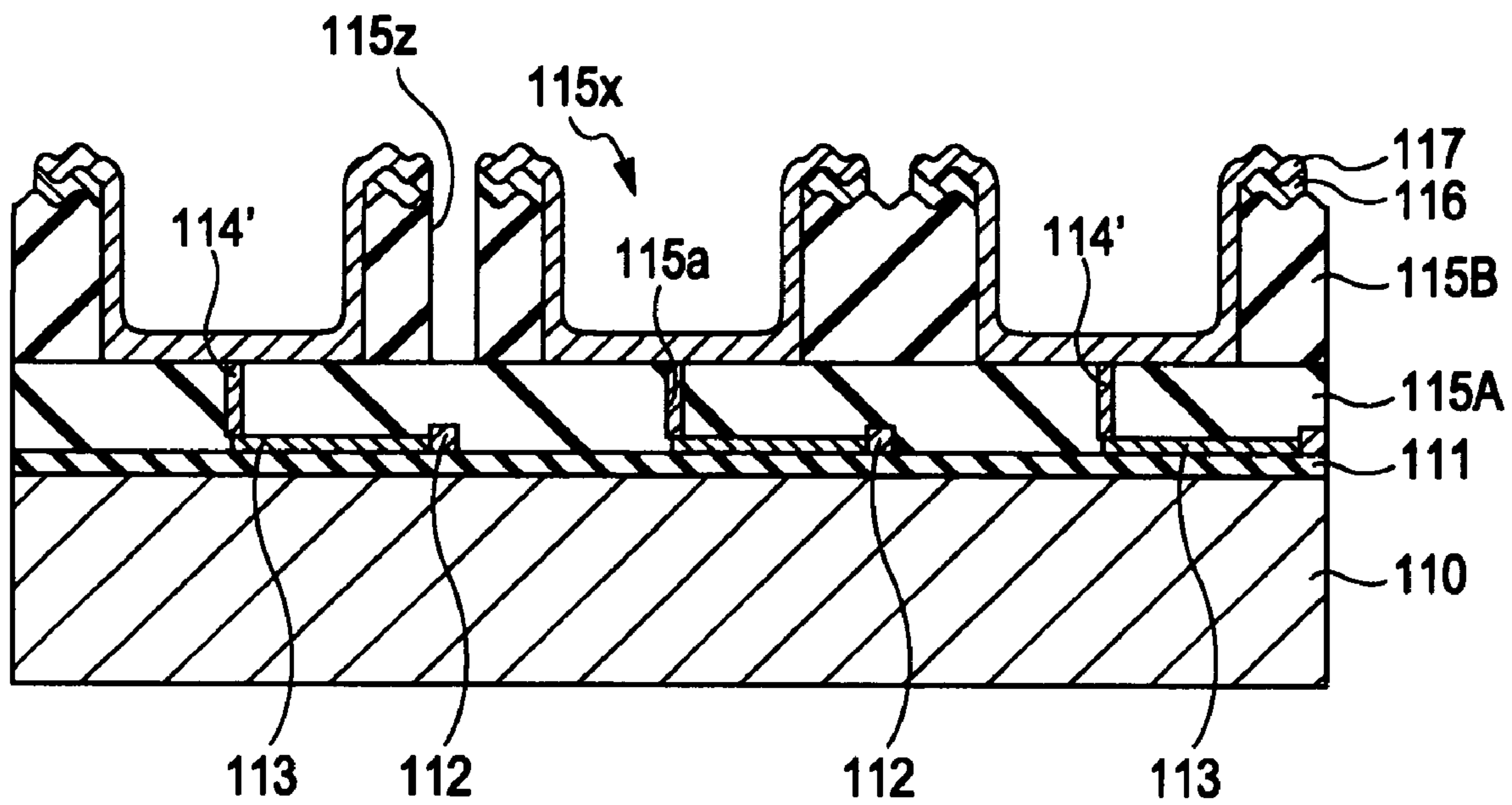


FIG. 6

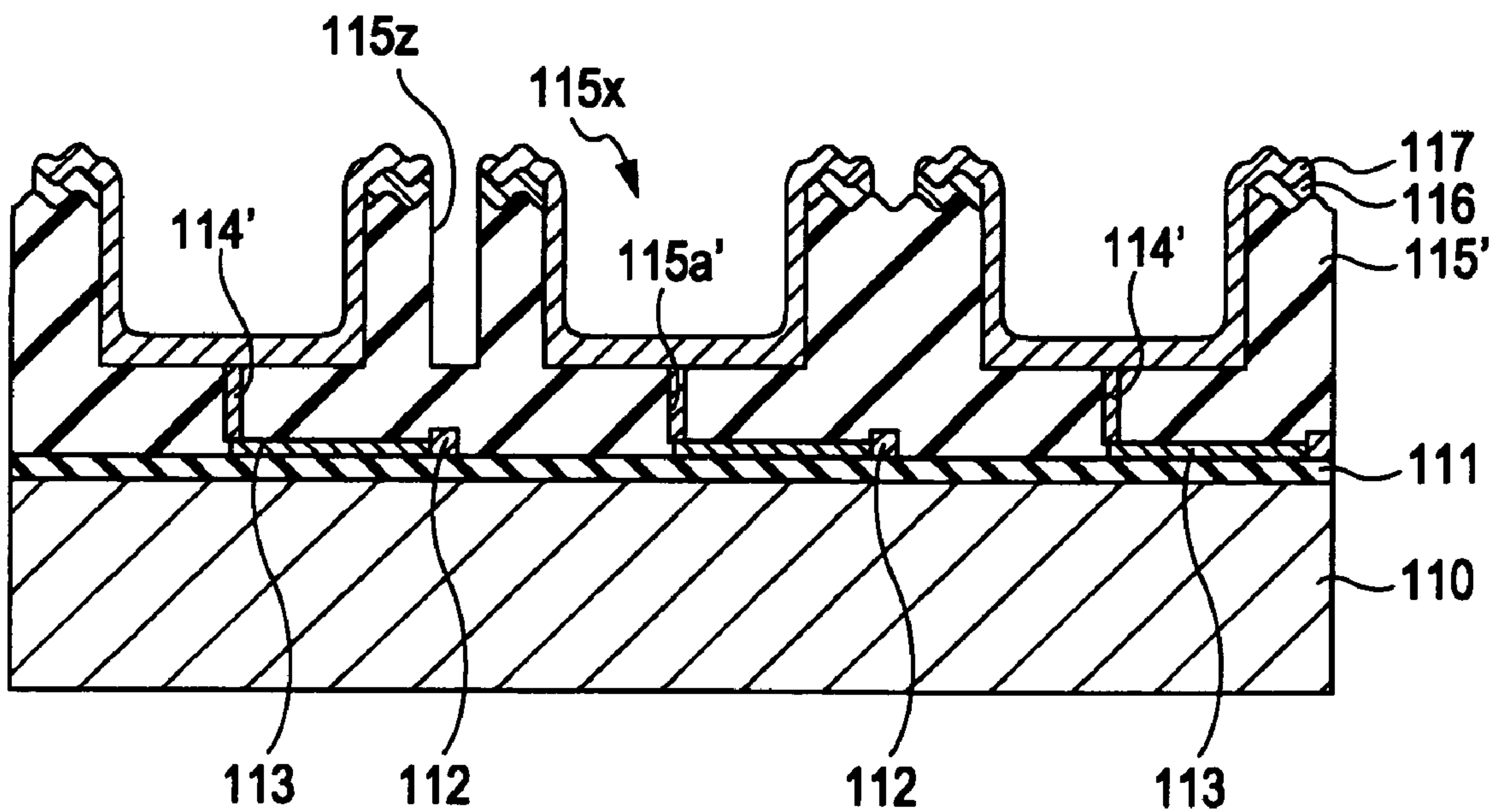


FIG. 7

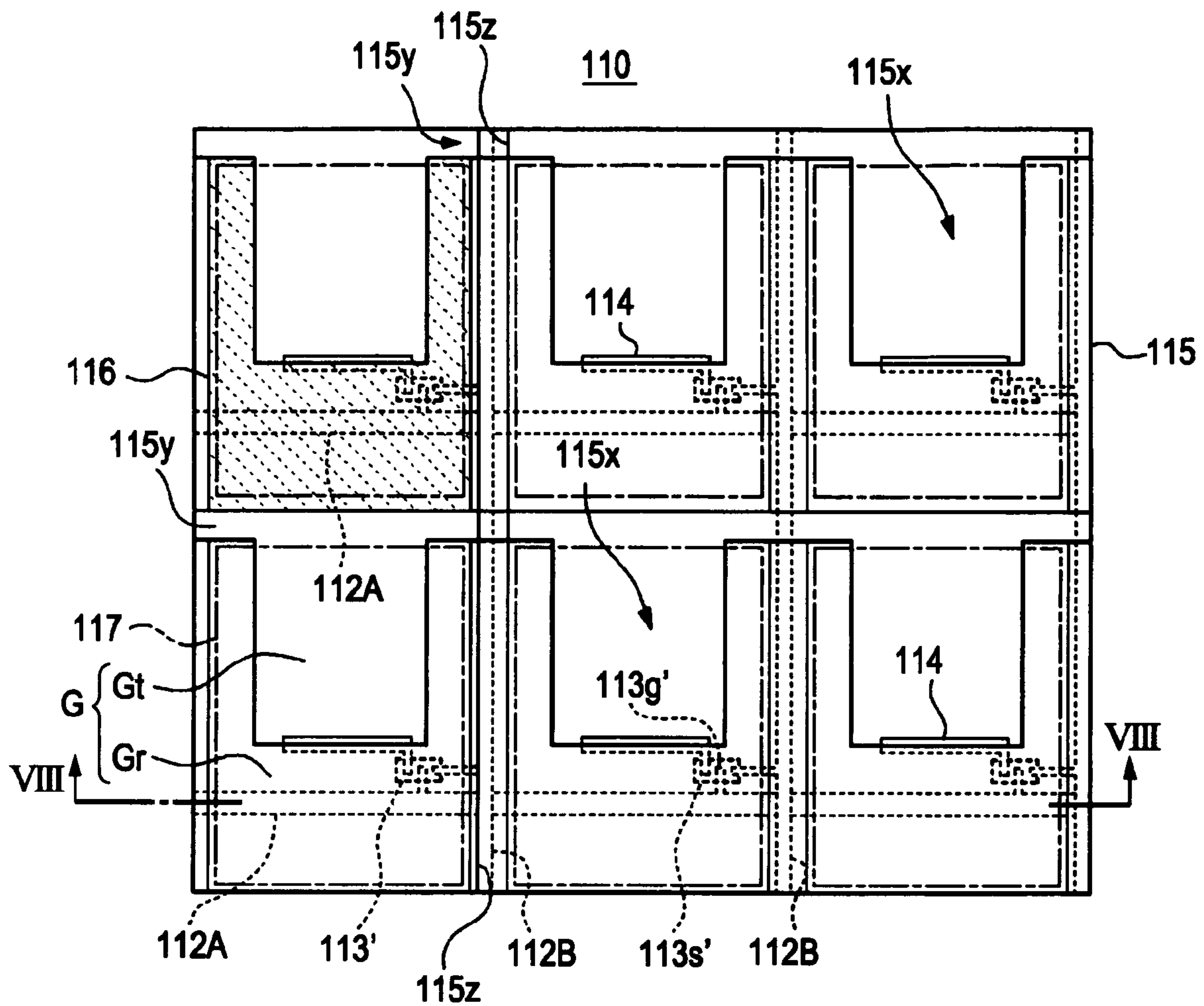


FIG. 8

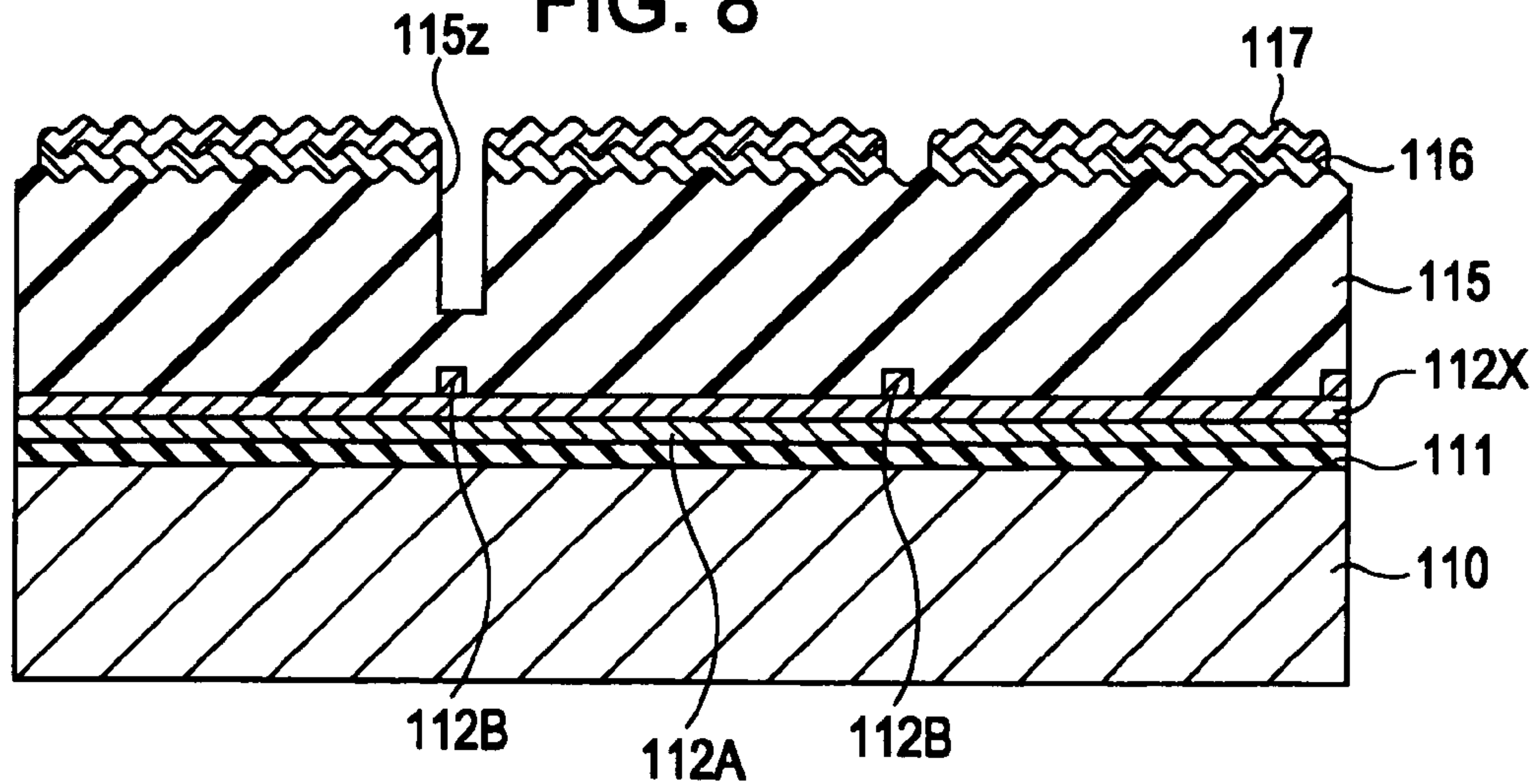


FIG. 9

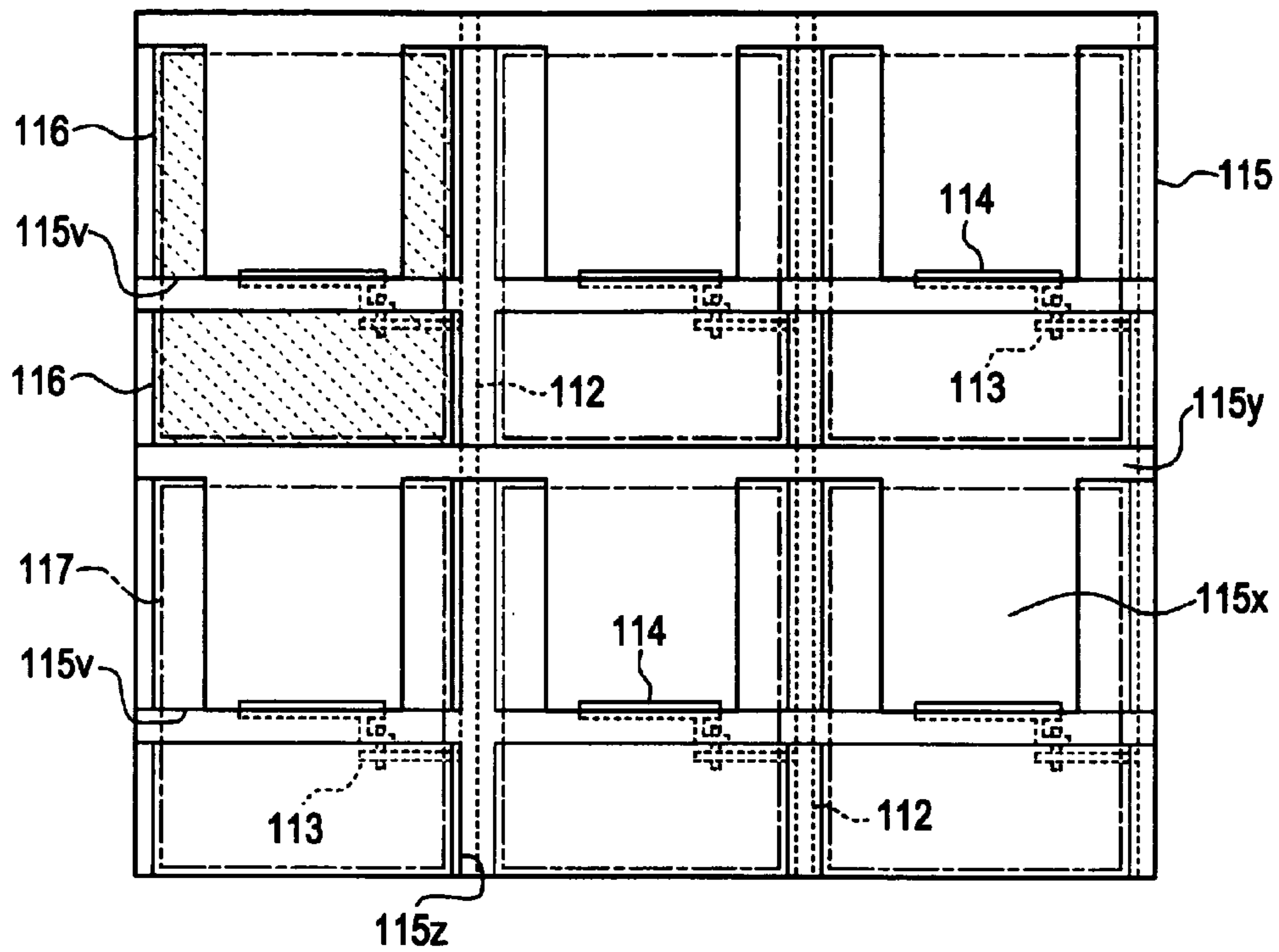


FIG. 10

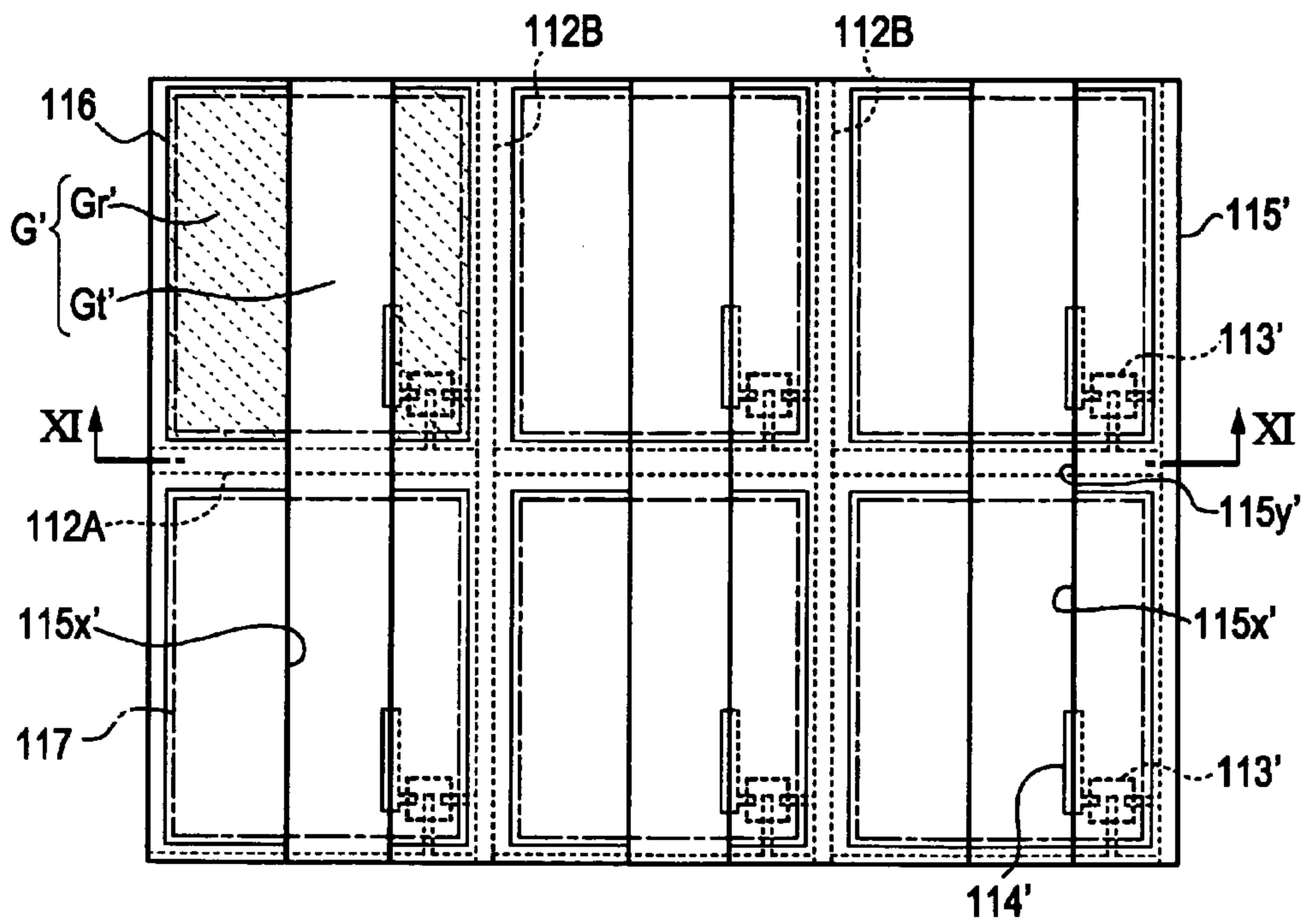


FIG. 11

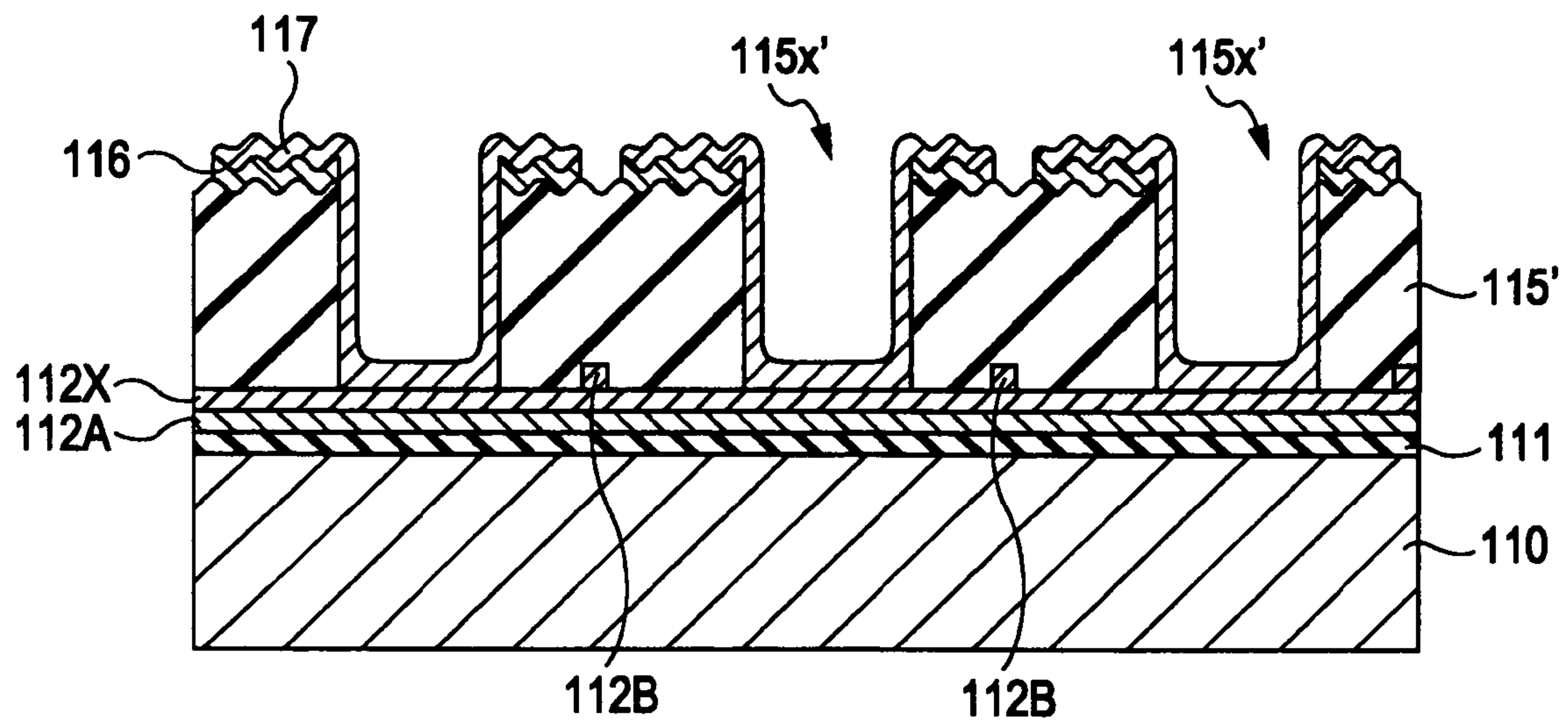
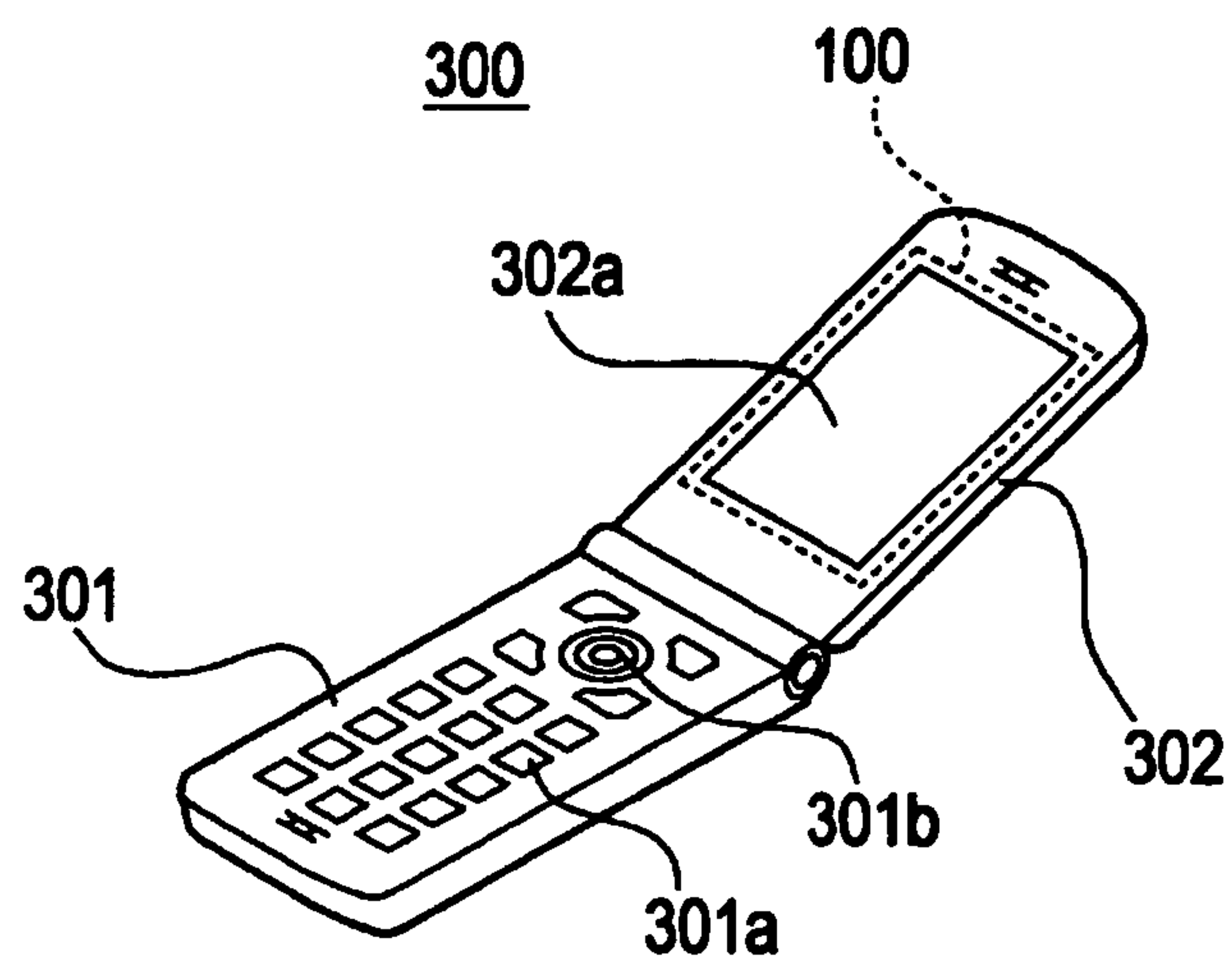


FIG. 12



LIQUID CRYSTAL DEVICE AND ELECTRONIC APPARATUS

BACKGROUND

1. Technical Field

The present invention relates to a liquid crystal device and an electronic apparatus, and more particularly, to an electrooptical device including a transmissive display region and a reflective display region in each sub-pixel.

2. Related Art

In general, liquid crystal devices have a cell structure in which liquid crystal is sealed between a pair of substrates, and an alignment film is provided on each of the substrates to regulate the initial alignment state of the liquid crystal. The alignment film is formed, for example, by applying unset resin, such as polyimide, onto the inner surface of each of the substrates by spin coating or printing, and drying or baking the resin.

Liquid crystal devices usually adopt a transmissive display method using transmitted light from a backlight, and a reflective display method using reflected external light. In particular, most mobile electronic apparatuses include a transmissive liquid crystal device capable of transmissive display and reflective display. In a transmissive liquid crystal device, sub-pixels are arranged in an effective driving region. Each of the sub-pixels includes a transmissive display region capable of transmissive display with a backlight, and a reflective display region capable of reflective display with external light.

In the transmissive liquid crystal device, transmitted light for transmissive display passes through a liquid crystal layer only once, whereas reflected light for reflective display passes through the liquid crystal layer twice. Therefore, the degree of retardation of display light caused by the liquid crystal layer substantially differs between transmissive display and reflective display. In order to reduce the difference in retardation between the transmissive display and the reflective display, the thickness of the liquid crystal layer in the reflective display region is usually set to be smaller than the thickness in the transmissive display region.

More specifically, the thickness of the liquid crystal layer is controlled by forming an insulating film on only a part of the inner surface of the substrate. That is, as disclosed in JP-A-2003-248222, a thick insulating film is provided in the reflective display region of the sub-pixel, and an insulating film is not provided or a thin insulating film is provided in the transmissive display region, so that the thickness of the liquid crystal layer sandwiched between the substrates is made different between the reflective display region and the transmissive display region.

However, in the above-described transmissive liquid crystal device, the insulating film is locally provided on the substrate, when an unset resin is applied on the substrate, it collects on regions where the insulating film is not provided (transmissive display regions). Consequently, the thickness of the alignment film becomes nonuniform, and display quality is lowered. Accordingly, JP-A-2004-325822 discloses that each recessed transmissive display region continuously extends through the adjoining pixels in order to enhance the fluidity of the alignment resin and to reduce nonuniformity of the thickness of the alignment film (particularly in FIGS. 3 and 13 to 17).

In the above-described improved liquid crystal device, fluidity of the alignment resin is enhanced because the recessed transmissive display region continuously extends through the pixels, whereas the problem of the nonuniform thickness of the alignment film is sometimes not solved satisfactorily. For

example, when an insulating film is patterned such that a reflective display region is also formed such as to continuously extend through pixels, the reflective display region is interposed between continuous transmissive display regions.

Therefore, the alignment resin entering from the reflective display region scatters in the extending direction of the transmissive display regions. Particularly at a peripheral edge of the transmissive display region close to the reflective display region, the thickness of the alignment film becomes nonuniform, and display quality is lowered. Further, when the alignment resin is applied by printing, degradation of display quality is sometimes inevitable, depending on the relationship between the printing direction and the extending direction of the transmissive display region.

A technique of forming an island-shaped reflective display region in each pixel is also adopted in the above-described liquid crystal device. In this case, a groove is provided between reflective display regions. Since the alignment resin can flow laterally and longitudinally (horizontally and vertically), it can be thought that nonuniformity of the thickness of the alignment film can be reduced. However, since the peripheral edge of the reflective display region is long compared with the area of the reflective display region, alignment defects of liquid crystal are easily caused by a height difference formed at the peripheral edge of the reflective display region, and display quality is lowered.

SUMMARY

An advantage of some aspects of the invention is that it provides a liquid crystal device that is highly resistant to degradation of display quality due to a nonuniform thickness of an alignment film thereof by preventing the flow of the alignment material constituting the alignment film from being hindered by an insulating film, and due to alignment defects of liquid crystal at a peripheral edge of the insulating film.

A liquid crystal device according to an aspect of the invention includes a pair of substrates, a liquid crystal layer provided between the substrates, and a plurality of sub-pixels each having a transmissive display region and a reflective display region. One of the substrates includes switching elements corresponding to the sub-pixels, lines connected to the switching elements, and an insulating film provided on the switching elements and the lines. The insulating film has first recesses provided in the transmissive display regions and second recesses provided along boundaries between the adjoining sub-pixels. At least a part of the insulating film other than the first and second recesses planarly overlaps with the reflective display regions. The thickness of the liquid crystal layer is smaller in the reflective display regions than in the transmissive display regions having the first recesses. The depth of the second recesses is smaller than the depth of the first recesses.

In this case, fluidity of an alignment material can be enhanced by the existence of the second recesses. Moreover, since the second recesses are disposed along the boundaries between the sub-pixels that are frequently shielded by any means, the influence on the display can be reduced. Since the depth of the second recesses is smaller than that of the first recesses, surface stepped portions in contact with the liquid crystal layer can be reduced, and the influence on the display can be reduced further. Even when lines are provided along the boundaries, a part of the insulating film remains under bottom portions of the second recesses because the depth of the second recesses is smaller than that of the first recesses. This prevents a short circuit.

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Preferably, the sub-pixels are arranged in a horizontal direction and a vertical direction, the first recesses are connected in the horizontal direction, and the second recesses extend along the boundaries between the sub-pixels adjoining in the horizontal direction. In this case, the first recesses are connected in the horizontal direction, and the second recesses having a depth smaller than the depth of the first recesses extend along the boundaries between the sub-pixels adjoining in the horizontal direction. Therefore, the alignment material can easily flow in both the horizontal and vertical directions.

Preferably, the sub-pixels are arranged in a horizontal direction and a vertical direction, the first recesses are connected in the horizontal direction, and the second recesses extend in the vertical direction. In this case, the first recesses are connected in the horizontal direction, and the second recesses having a depth smaller than the depth of the first recesses extend in the vertical direction. Therefore, the alignment material can easily flow in both the horizontal and vertical directions.

Preferably, the sub-pixels are arranged in a horizontal direction and a vertical direction, each of the second recesses includes a portion extending in the horizontal direction and a portion extending in the vertical direction. In this case, the alignment material can easily flow in both the horizontal and vertical directions.

A liquid crystal device according to another aspect of the invention includes a pair of substrates, a liquid crystal layer provided between the substrates, and a plurality of sub-pixels each having a transmissive display region and a reflective display region. One of the substrates includes switching elements corresponding to the sub-pixels, lines connected to the switching elements, and an insulating film provided on the switching elements and the lines. The insulating film has first recesses provided in the transmissive display regions, and second recesses provided above the lines. At least a part of the insulating film other than the first and second recesses planarly overlaps with the reflective display regions. The thickness of the liquid crystal layer is smaller in the reflective display regions than in the transmissive display regions having the first recesses. The depth of the second recesses is smaller than the depth of the first recesses.

In this case, fluidity of the alignment material can be enhanced by existence of the second recesses. Moreover, since the second recesses are disposed in the portions above the lines that are frequently shielded by the lines or any other means, the influence on the display can be reduced. Since the depth of the second recesses is smaller than that of the first recesses, surface stepped portions in contact with the liquid crystal layer can be reduced, and the influence on the display can be reduced further. In addition, since the depth of the second recesses is smaller than that of the first recesses, a part of the insulating film remains under bottom portions of the second recesses. This prevents a short circuit.

Preferably, the second recesses are grooves extending along the lines. In this case, the fluidity of the alignment material can be enhanced further. Moreover, since the second recesses can be disposed along the boundaries between the adjoining sub-pixels, the influence on the display can be reduced.

Preferably, the sub-pixels are arranged in a horizontal direction and a vertical direction, the first recesses are connected in the horizontal direction, and the second recesses extend in the vertical direction. In this case, the first recesses are connected in the horizontal direction, and the second recesses having a depth smaller than the depth of the first

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recesses extend in the vertical direction. Therefore, the fluidity of the alignment material can be enhanced while reducing the influence on the display.

Preferably, the sub-pixels are arranged in a horizontal direction and a vertical direction, and the lines extend in the vertical direction. The liquid crystal device may further include lower lines extending in the horizontal direction below the lines, and an interlayer insulating layer provided between the lines and the lower lines. Since the interlayer insulating layer is disposed on the lower lines, a short circuit due to the lower lines rarely occurs. However, since the lines are disposed on the interlayer insulating layer, a short circuit due to the lines easily occurs. Therefore, the configuration of this aspect of the invention is particularly effective.

A liquid crystal device according to a further aspect of the invention includes a pair of substrates, a liquid crystal layer provided between the substrates, and a plurality of sub-pixels each having a transmissive display region and a reflective display region. One of the substrates includes switching elements corresponding to the sub-pixels, lines connected to the switching elements, an insulating film provided on the switching elements and the lines, and a reflecting layer provided on the insulating film in the reflective display regions. The lines extend along boundaries between the adjoining sub-pixels. The insulating film includes first recesses provided in the transmissive display regions, and second recesses provided along the lines. At least a part of the insulating film other than the first and second recesses planarly overlaps with the reflective display regions. The thickness of the liquid crystal layer is smaller in the reflective display regions than in the transmissive display regions having the first recesses. A part of the insulating film in a thickness direction is provided between the lines and inner bottom portions of the second recesses.

In this case, since the insulating film has the second recesses outside the transmissive display regions, it is possible to enhance the fluidity of the alignment material while reducing the influence on the display. Moreover, since a part of the insulating film in the thickness direction is interposed between the lines and the second recesses, a short circuit due to the lines and the second recesses can be prevented.

Preferably, the insulating film includes a lower insulating layer provided in the transmissive display regions and the reflective display regions, and an upper insulating layer provided in the reflective display regions. Preferably, the lower insulating layer is interposed between the lines and the inner bottom portions of the second recesses.

A liquid crystal device according to a further aspect of the invention includes a pair of substrates, a liquid crystal layer provided between the substrates, and a plurality of sub-pixels arranged in a horizontal direction and a vertical direction, each of the sub-pixels having a transmissive display region and a reflective display region. One of the substrates includes switching elements corresponding to the sub-pixels, upper lines extending in the vertical direction and lower lines extending in the horizontal direction, the upper and lower lines being connected to the switching elements, an interlayer insulating layer provided between the upper lines and the lower lines, and an insulating film provided on the upper lines. The insulating film includes recesses provided in the transmissive display regions and connected along the sub-pixels adjoining in the vertical direction. A portion of the insulating film other than the recesses covers the upper lines. At least a part of the portion of the insulating film other than the recesses planarly overlaps with the reflective display

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regions. The thickness of the liquid crystal layer is smaller in the reflective display regions than in the transmissive display regions having the recesses.

In this case, the recesses of the insulating layer provided in the transmissive display regions are connected in the vertical direction such as to cross the lower lines extending in the horizontal direction, and the upper lines extending in the vertical direction are covered with the portion of the insulating film other than the recesses. Consequently, it is possible to prevent a short circuit due to the lines and the recesses while ensuring high fluidity of the alignment material.

Preferably, the liquid crystal device further includes pixel electrodes electrically connected to the switching elements in the respective sub-pixels, and contacts between the switching elements and the pixel electrodes are provided at edges of inner bottom portions of the recesses. In this case, since electrical contacts between the switching elements and the pixel electrodes can be obtained by using the recesses of the insulating film, there is no need to perform a step of forming contact holes.

An electronic apparatus according to a still further aspect of the invention includes any of the liquid crystal devices as a display unit. While the type of the electronic apparatus is not particularly limited, a mobile electronic apparatus, such as a mobile telephone, a mobile computer, or a mobile electronic watch, is particularly effective because transmissive display in the transmissive display region and reflective display in the reflective display region are both possible.

A liquid-crystal-device manufacturing method according to a still further aspect of the invention manufactures a liquid crystal device including a pair of substrates, a liquid crystal layer provided between the substrates, and a plurality of sub-pixels each having a transmissive display region and a reflective display region. The liquid-crystal-device manufacturing method includes forming switching elements corresponding to the sub-pixels and lines connected to the switching elements on one of the substrates; forming an insulating film on the switching elements and the lines, the insulating film including first recesses provided in the transmissive display regions and second recesses provided along boundaries between the adjoining sub-pixels, at least a part of the insulating film other than the first and second recesses planarly overlapping with the reflective display regions, and the second recesses having a depth smaller than a depth of the first recesses; forming an alignment film by applying an alignment material on the substrate such that the alignment material flows in the first and second recesses; and placing the liquid crystal layer, the liquid crystal layer being thinner in the reflective display regions than in the transmissive display regions having the first recesses.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements.

FIG. 1 is a schematic plan view of a first substrate in a liquid crystal device according to a first embodiment of the invention.

FIG. 2 is a schematic longitudinal sectional view of the first substrate, taken along line II-II in FIG. 1.

FIG. 3 is a schematic longitudinal sectional view of the first substrate, taken along line III-III in FIG. 1.

FIG. 4 is a schematic longitudinal sectional view of the liquid crystal device according to the first embodiment.

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FIG. 5 is a schematic longitudinal sectional view of a first substrate in a liquid crystal device according to a second embodiment of the invention.

FIG. 6 is a schematic longitudinal sectional view of a first substrate in a liquid crystal device according to a third embodiment of the invention.

FIG. 7 is a schematic plan view of a first substrate in a liquid crystal device according to a fourth embodiment of the invention.

FIG. 8 is a schematic longitudinal sectional view of the first substrate, taken along line VIII-VIII in FIG. 7.

FIG. 9 is a schematic plan view of a first substrate in a liquid crystal device according to a fifth embodiment of the invention.

FIG. 10 is a schematic plan view of a first substrate in a liquid crystal device according to a sixth embodiment of the invention.

FIG. 11 is a schematic longitudinal sectional view of the first substrate, taken along line XI-XI in FIG. 10.

FIG. 12 is a schematic perspective view of an electronic apparatus.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

First Embodiment

Embodiments of the invention will now be described in detail with reference to the attached drawings. FIG. 1 is a schematic plan view of a substrate **110** in a liquid crystal device **100** according to a first embodiment, FIG. 2 is a schematic longitudinal sectional view, taken along line II-II in FIG. 1, FIG. 3 is a schematic longitudinal sectional view, taken along line III-III in FIG. 1, and FIG. 4 is an enlarged longitudinal sectional view of the liquid crystal device **100**. It should be noted that all the dimensions and dimensional ratios shown in the attached figures are appropriately set for convenience of drawing, and do not represent actual dimensions and dimensional ratios.

The liquid crystal device **100** according to the first embodiment has a panel structure in which a pair of substrates, namely, a first substrate **110** and a second substrate **120** are bonded with a sealing material (not shown), and liquid crystal **131** is sealed therebetween, as shown in FIG. 4. The first substrate **110** is an array substrate (element substrate) including lines and elements, and the second substrate **120** is a color filter substrate (counter substrate) including a color filter.

As shown in FIGS. 1 and 4, sub-pixels **G** are arranged in a horizontal direction (a right-left direction in FIGS. 1 and 4) and in a vertical direction (an up-down direction in FIG. 1, a direction perpendicular to the plane of FIG. 4). Each of the sub-pixels **G** includes a reflective display region **Gr** in which light incident from the second substrate **120** is reflected by a reflecting layer **116** that will be described below, and a transmissive display region **Gt** in which the reflecting layer **116** is not provided and through which incident light passes.

An insulating layer **111** formed of, for example, Ta_2O_5 or SiO_2 is provided on the first substrate **110**. On the insulating layer **111**, a metal line **112** of, for example, Ta, Ta—W, or Al is provided in each sub-pixel column defined by a plurality of sub-pixels **G** arranged in the vertical direction. The line **112** vertically extends along the boundaries between the sub-pixels **G** adjoining in the horizontal direction. While the line **112** is provided on the boundaries in the figures, in actuality, it may be shifted from the boundaries in the horizontal direction.

The line **112** is electrically connected to an element **113** provided in each sub-pixel **G**. The element **113** is electrically connected to a contact electrode **114**. In the first embodiment, the element **113** is a TFD (a thin film transistor, a metal-insulator-metal element) serving as a two-terminal nonlinear element, and has a back-to-back structure in which two TFD element structures having opposite polarities are connected in series, as shown in FIG. 1.

The lines **112**, the elements **113**, and the contact electrodes **114** are formed by known methods using a conductor forming process such as vapor deposition or sputtering, an insulator forming process such as anodic oxidation or CVD, and patterning such as photolithography or etching.

A transparent insulating film **115** formed of acrylic resin or the like is provided on the lines **112** and the elements **113**. The insulating film **115** is formed by film deposition such as printing, spin coating, or CVD, and patterning such as photolithography or etching so that a predetermined pattern is provided in each sub-pixel **G**. The insulating film **115** does not exist in the transmissive display region **Gt**, but exists in the reflective display region **Gr**. When the insulating film **115** is formed of a transparent material, a part of the insulating film **115** in the thickness direction may exist in the transmissive display region **Gt**. That is, in the first embodiment, recesses are provided in the insulating film **115** such that the thickness of the liquid crystal layer **131** is larger in the transmissive display region **Gt** than in the reflective display region **Gr**.

The insulating film **115** has the same pattern in each pixel **P** serving as the minimum display unit defined by a plurality of sub-pixels **G**. The pixel **P** is constituted by a plurality of types of sub-pixels **G** corresponding to a plurality of color layers **121R**, **121B**, and **121G** in a color filter **121** that will be described below. More specifically, one pixel **P** is constituted by three sub-pixels **G** adjoining in the horizontal direction.

On the first substrate **110**, the insulating film **115** is not provided in the transmissive display regions **Gt** and in regions along the boundaries between the sub-pixels **G** adjoining in the vertical direction, and these regions serve as recesses. Recesses **115x** provided in the transmissive display regions **Gt** of the sub-pixels **G** adjoining in the horizontal direction are connected by recesses **115y** provided in the regions along the boundaries between the sub-pixels **G** adjoining in the vertical direction.

The insulating film **115** also includes grooves **115z** provided along the sub-pixels **G** adjoining in the horizontal direction. The depth of the grooves **115z** is smaller than the thickness of the insulating film **115**. That is, inner bottom portions of the grooves **115z** are disposed higher than a lower surface of the insulating film **115** (a plane on which the insulating film **115** is provided), and portions of the insulating film **115** in the thickness direction remain under the inner bottom portions. Below the grooves **115z**, the above-described lines **112** extend parallel to the grooves **115z** (that is, in the vertical direction).

In the first embodiment, the groove **115z** extends only along the boundary between a red sub-pixel **G** in which a below-described red color layer is provided (a left sub-pixel in FIGS. 1 and 4) and a blue sub-pixel **G** in which a blue color layer is provided (a center sub-pixel in FIGS. 1 and 4) in each pixel **P**. This is because alignment failure is less conspicuous at the boundary between the red and blue sub-pixels than at the boundary between the blue sub-pixel and a green sub-pixel (a right sub-pixel in FIGS. 1 and 4) or than at the boundary between the green and red sub-pixels. However, the groove **15z** may be provided at any of these boundaries.

Preferably, the insulating film **115** is formed of a transparent material, and particularly, a resin material. For example,

the insulating **115** can be formed of a resin material by photolithography using a half-tone mask. More specifically, the insulating film **115** can be formed by applying a positive photosensitive resin by, for example, printing, exposing the resin with a photomask including transmissive portions corresponding to the recesses **115x** and **115y**, semitransmissive portions corresponding to the grooves **115z**, and shielding portions corresponding to the other portions, and then developing the exposed resin. When a negative photosensitive resin is used, the relationship between the transmissive portions and the shielding portions is inverted.

Preferably, the insulating film **115** has fine surface irregularities. When the insulating film **115** is formed by the above-described lithography, the surface irregularities can be formed with a photomask in which minute transmissive portions are scattered.

The above-described contact electrode **114** is exposed under a stepped portion provided between the reflective display region **Gr** and the transmissive display region **Gt** at an edge of the insulating film **115**, that is, at an edge of the inner bottom portion of the recess **115x**. The contact electrode **114** is electrically connected to a pixel electrode **117** that will be described below.

A reflecting layer **116** formed of a light reflective material having high reflectance, such as **Al** or **Ag**, is provided on the insulating film **115**. The reflecting layer **116** is disposed corresponding to the reflective display region **Gr** of the sub-pixel **G**, that is, on the insulating film **115** in the sub-pixel **G**. The reflecting layer **116** has a scattering reflecting surface with fine irregularities corresponding to the fine surface irregularities of the insulating film **115**. Since the reflecting layer **116** is formed of a conductive material (metallic material) in the first embodiment, it may be electrically connected to the contact electrode **114**.

A pixel electrode **117** formed of a transparent conductor such as **ITO** (indium tin oxide) is provided in the sub-pixel **G**. The pixel electrode **117** is electrically connected to the contact electrode **114** directly or via the reflecting layer **116**.

On the other hand, color layers **121R**, **121B**, and **121G** are arranged on the second substrate **120** in a predetermined pattern, as shown in FIG. 4. In the color layers **121R**, **121B**, and **121G**, a coloring agent, such as dye or pigment, is dispersed in a transparent resin base material such as acrylic resin. In the first embodiment, color layers of the same color are arranged in the vertical direction, and color layers of different colors are alternately arranged in the horizontal direction, thus constituting a striped color filter **121**. The color layers **121R**, the color layers **121B**, and the color layers **121G** constitute a red filter element, a blue filter element, and a green filter element, respectively. A shielding portion can be provided between the color layers of different colors. For example, the shielding portion is formed by overlapping the adjoining different color layers at the boundary between the sub-pixels adjoining in the horizontal direction. Alternatively, the shielding layer may be formed of a metallic film or a shielding material such as black resin. In the first embodiment, the shielding portion is a shielding layer **121BM** of black resin above the groove **115z**. This is because alignment failure of liquid crystal is easily caused by a height difference formed on the first substrate **110** by the groove **115z**, and consequently, contrast failure due to light leakage occurs in the region where the groove **115z** is disposed.

A transparent protective film **122** made of, for example, acrylic resin, is provided on the color filter **121**. The transparent protective film **122** serves to prevent degradation of the color layers due to the entry of impurities, and to flatten the surface of the color filter **121**.

A counter electrode (common electrode) **123** formed of a transparent conductor, such as ITO, is provided on the transparent protective film **122**. When the elements **113** are two-terminal nonlinear elements, as in the first embodiment, the counter electrode **123** is formed by a plurality of belt-shaped electrodes extending horizontally and arranged in parallel in the vertical direction, that is, in stripes as a whole. When the elements **113** are three-terminal nonlinear elements like TFTs, a single common electrode is provided such as to commonly face a plurality of sub-pixels G arranged in the horizontal and vertical directions.

A spacer **132** shown in FIG. 4 is made of an insulating resin, and is formed on the first substrate **110** by photolithography. The spacer **132** may be fixed to one of the substrates, or may be placed without being fixed to any of the substrates. Alternatively, the spacer **132** may be omitted from the display region by mixing a spacer material in the sealing material.

Alignment films **118** and **124** are respectively formed on inner surfaces of the first and second substrates **110** and **120** having the above-described structures, for example, by applying an alignment material, such as an alignment resin, and baking or drying the alignment material. Typically, a polyimide resin is applied by printing (e.g., letterpress printing) or spin coating, and is then baked at a predetermined temperature. When the alignment films **118** and **124** thus formed do not have a liquid crystal aligning ability, they are subjected to aftertreatment such as rubbing, as required.

Since the surface of the first substrate **110** is uneven because of the surface irregularities of the insulating film **115**, the flow of the applied alignment material is sometimes hindered, and the thickness of the alignment film becomes non-uniform particularly in the transmissive display regions. Consequently, alignment defects of liquid crystal occur, and display becomes uneven. However, in the first embodiment, the recesses **115x** provided in the transmissive display regions Gt are horizontally connected by the recesses **115x**, and the grooves **115z** extend vertically. Therefore, the alignment material can easily flow in both the horizontal and vertical directions, and display unevenness can be reduced. In particular, since the grooves **115z** extend such that the recesses **115x** and **115y** in the sub-pixels G adjoining in the vertical direction communicate with each other, fluidity of the alignment material in the vertical direction can be enhanced.

Further, the recesses **115y** extend along the boundaries between the sub-pixels G adjoining the vertical direction, and the grooves **115z** extend along the boundaries between the sub-pixels G adjoining in the horizontal direction. Therefore, it is possible to reduce the influence of alignment defects of liquid crystal due to the height differences, which are formed by the recesses or the grooves, on the display. In particular, since the depth of the grooves **115z** is smaller than the thickness of the insulating layer **115**, the height differences themselves are reduced, and alignment defects of liquid crystal due to the grooves **115z** are reduced further.

While each groove **115z** extends along the line **112** (above the line **112** in the first embodiment), since a part of the insulating film **115** in the thickness direction remains under the groove **115z**, a short circuit of the line **112** to the reflecting layer **116** and the pixel electrode **117** can be prevented.

Preferably, a portion of the insulating layer **115** in the thickness direction, for example, a portion of the insulating layer **115** having a thickness equal to the thickness of the inner bottom portion of the groove **115z** remains at the intersection of the recess **115y** and the groove **115z** in order to shield the line **112**. However, the insulating film **115** may be entirely removed at the intersection.

While the recesses **115x** provided in the transmissive display regions Gt are connected in the horizontal direction by the narrow recesses **115y** extending along the boundaries between the sub-pixels G adjoining in the vertical direction in the first embodiment, the width of the recesses **115y** in the vertical direction may be set to be equal to the width of the recesses **115x** in the vertical direction so that belt-shaped recesses horizontally extend through the transmissive display regions Gt.

Second Embodiment

A liquid crystal device according to a second embodiment of the invention will now be described with reference to FIG. 5. In the second embodiment, components similar to those in the first embodiment are denoted by the same reference numerals, and descriptions thereof are omitted. It should be noted that structures that are not shown in the figure are similar to the first embodiment.

In the second embodiment, a transparent lower insulating layer **115A** is provided on lines **112** and elements **113** that are similar to those in the first embodiment. An upper insulating layer **115B** is provided on the lower insulating layer **115A**. The upper insulating layer **115B** does not need to be formed of a transparent material. Similarly to the insulating layer **115** in the first embodiment, the upper insulating layer **115B** is patterned to form recesses **115x** and grooves **115z**. The recesses **115x** and the grooves **115z** are formed at portions where the upper insulating layer **115B** is not provided. Therefore, inner bottom portions of the recesses **115x** and the grooves **115z** are formed by a surface of the lower insulating layer **115A**. A surface of the upper insulating layer **115B** has fine irregularities, and a reflecting layer **116** provided on the surface forms a scattering reflecting surface, in a manner similar to that in the first embodiment.

Contact electrodes **114'** electrically connected to the elements **113** are respectively provided in contact holes **115a** provided in the lower insulating layer **115A**, and are electrically connected to pixel electrodes **117** disposed on the lower insulating layer **115A** via the contact holes **115a**. The contact holes **115a** may be formed by performing a patterning step after the recesses **115x** and the grooves **115z** by patterning the upper insulating layer **115B**, or may be formed together with the recesses **115x** and the grooves **115z** by photolithography using a half-tone mask after the lower insulating layer **115A** and the upper insulating layer **115B** made of photosensitive resin are stacked.

Since the lower insulating layer **115A** is provided between the lines **112** and the inner bottom portions of the grooves **115z**, when a combination of the lower insulating layer **115A** and the upper insulating layer **115B** corresponds to the insulating film in the first embodiment, a part of the insulating film is interposed between the lines **112** and the inner bottom portions of the grooves **115z**, similarly to the first embodiment. Therefore, it is possible to reliably prevent a short circuit of the lines **112** to a reflecting layer **116** and the pixel electrodes **117**.

While the depth of the grooves **115z** is equal to the depth of the recesses **115x** in the second embodiment, it may be smaller than the depth of the recesses **115x** as in the first embodiment.

Third Embodiment

A liquid crystal device according to a third embodiment of the invention will now be described with reference to FIG. 6. In the third embodiment, the lower insulating layer **115A** and

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the upper insulating layer **115B** in the second embodiment are replaced with a single insulating film **115'**. Since other structures are similar to those in the second embodiment, they are denoted by the same reference numerals, and descriptions thereof are omitted.

The depths of recesses **115x** and grooves **115z** are smaller than the thickness of the insulating film **115'**, and a part of the insulating film **115'** in the thickness direction remains under inner bottom portions of the recesses **115x** and the grooves **115z**. Since the part of the insulating film **115'** in the thickness direction is interposed between lines **112** and the inner bottom portions of the grooves **115z**, similarly to the second embodiment, a short circuit can be prevented.

After the lines **112** and elements **113** are formed, the insulating film **115'** is formed, and the recesses **115x**, the grooves **115z**, and contact holes **115a'** are then formed. Subsequently, contact electrodes **114** are formed in the contact holes **115a'**, and a reflecting layer **116** and pixel electrodes **117** are formed. When the insulating film **115'** is patterned, formation of the recesses **115x** and the grooves **115z** and formation of the contact holes **115a'** may be performed in separate steps, as in the second embodiment, or may be simultaneously performed by using a half-tone mask or the like.

While the depth of the grooves **115z** is equal to the depth of the recesses **115x** in the third embodiment, it is more preferable that the depth of the grooves **115z** be smaller than the depth of the recesses **115x**, in a manner similar to that in the first embodiment.

Fourth Embodiment

A fourth embodiment of the invention will now be described with reference to FIGS. 7 and 8. In the fourth embodiment, the same components as those in the first embodiment are denoted by the same reference numerals, and descriptions thereof are omitted. Components that are not shown in the figures are basically similar to those in the first embodiment, unless otherwise specified.

Unlike the above-described embodiments, elements **113'** provided in respective sub-pixels **G** in the fourth embodiment are three-terminal nonlinear elements such as TFTS. Therefore, lower horizontal lines (scanning lines) **112A** and upper vertical lines (signal lines) **112B** are connected to the elements **113'**. A counter electrode is provided on a second substrate (not shown) as a common electrode such as to face all sub-pixels **G**.

An interlayer insulating layer **112X** is provided on the lower lines **112A**, and the upper lines **112B** are provided thereon.

Each element **113'** includes a gate electrode **113g'** electrically connected to the line **112A** (or provided integrally with the line **112A**), and a semiconductor layer **113s'** opposing the gate electrode **113g'** with an unshown gate insulating layer therebetween, and formed of polycrystalline silicon or amorphous silicon. A portion of the semiconductor layer **113s'** on one side of a channel region facing the gate electrode **113g'** is electrically connected to the line **112B**, and a portion thereof on the other side of the channel region is electrically connected to a contact electrode **114**. The contact electrode **114** is exposed at an edge of an inner bottom portion of a recess **115x**, and is electrically connected to a pixel electrode **117**, in a manner similar to that in the first embodiment.

While the lower lines **112A** are not easily short-circuited because the interlayer insulating layer **112X** is provided thereon, the upper lines **112B** are easily short-circuited to a reflecting layer **116** and the pixel electrode **117** if grooves

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115z are formed through an insulating film **115** in the thickness direction. This is because only the insulating film **115** is provided on the lines **112B**.

In the fourth embodiment, however, since the depth of the groove **115z** is smaller than the thickness of the insulating film **115**, a part of the insulating film **115** in the thickness direction remains under the inner bottom portion of the groove **115z**. This prevents a short circuit between the upper lines **112B**, and the reflecting layer **116** and the pixel electrodes **117**.

Fifth Embodiment

A fifth embodiment of the invention will now be described with reference to FIG. 9. In the fifth embodiment, the same components as those in the first embodiment are denoted by the same reference numerals, and descriptions thereof are omitted. Components that are not shown in the figure are basically similar to those in the first embodiment, unless otherwise specified.

FIG. 9 is a schematic plan view of a first substrate **110** adopted in the fifth embodiment. The fifth embodiment is different from the first embodiment in that horizontally extending grooves **115v** are further provided. Each groove **115v** extends along the boundaries between transmissive display regions **Gt** and reflective display regions **Gr** in a plurality of sub-pixels **G** adjoining in the horizontal direction. Similarly to the above-described grooves **115z**, the depth of the grooves **115v** is smaller than the depth of recesses **115x** provided in the transmissive display regions **Gt**. A contact electrode **114** is exposed at an edge of an inner bottom portion of each recess **115x**, and is electrically connected to a pixel electrode **117**, in a manner similar to that in the first embodiment.

The addition of the grooves **115v** allows an alignment material to more easily flow between the recesses **115x** in the horizontal direction. While a recess **115y** extends on one vertical side of the recess **115x** in the transmissive display region **Gt**, the groove **115v** faces the other vertical side of the recess **115x**. Therefore, fluidity of the alignment material in the horizontal direction is enhanced on both sides of the recess **115x**. This further reduces display unevenness.

Since the groove **115v** is provided above an element **113**, if it has a depth similar to that of the recess **115x** provided in the transmissive display region **Gt**, a risk of a short circuit between the element **113**, and a reflecting layer **116** and the pixel electrode **117** is increased. In the fifth embodiment, however, since the depth of the groove **115v** is smaller than that of the recess **115x**, a short circuit can be prevented.

Sixth Embodiment

A sixth embodiment of the invention will now be described with reference to FIG. 10 and 11. In the sixth embodiment, the same components as those in the fourth embodiment are denoted by the same reference numerals, and descriptions thereof are omitted.

FIGS. 10 and 11 are a schematic plan view and a schematic longitudinal sectional view, respectively, of a first substrate. In the sixth embodiment, recesses **115x'** are provided in transmissive display regions **Gt'** of sub-pixels **G'**, and are connected in the vertical direction along a plurality of sub-pixels **G'**. More specifically, recesses **115y'** are provided at the boundaries between sub-pixels **G'** adjoining in the vertical direction, and the recesses **115x'** are connected in the vertical direction by the recesses **115y'**.

The recess **115x'** and the recess **115y'** have the same horizontal width, and constitute a belt-shaped integral recess extending vertically. That is, a plurality of belt-shaped recesses are arranged in parallel in the horizontal direction, that is, in stripes as a whole. While a reflective display region **Gr'** is provided on each horizontal side of the transmissive display region **Gt'** in each sub-pixel **G'**, it may be provided only one side. Upper lines **112B** extending vertically are completely shielded by portions of an insulating film **115'** other than the recesses.

While lower lines **112A**, an interlayer insulating layer **112X**, and the upper lines **112B** are provided, as in the fourth embodiment, the transmissive display regions **Gt'** are connected in the vertical direction by the recesses **115x'** and the **115y'**. In this case, the recesses connected in the vertical direction extend across the lines **112A**. Since the lines **112A** are disposed under the interlayer insulating layer **112X**, a short circuit does not occur. On the other hand, since the upper lines **112B** are completely shielded by the portions of the insulating film **115'** other than the recesses, a short circuit due to the lines **112B** does also not occur. A contact electrode **114** is exposed at an edge of an inner bottom portion of each recess **115x'**, and is electrically connected to a pixel electrode **117**, in a manner similar to that in the first embodiment.

Electronic Apparatus

Finally, a description will be given of an electronic apparatus including the above-described liquid crystal device **100**. FIG. **12** is a schematic perspective view of an electronic apparatus.

FIG. **12** shows a mobile telephone **300** serving as an electronic apparatus according to an embodiment of the invention. The mobile telephone **300** includes an operation unit **301** having a plurality of operation buttons **301a** and **301b** and a mouthpiece, and a display unit **302** having a display screen **302a** and an earpiece. The above-described liquid crystal device **100** is incorporated in the display unit **302**. A display image formed by the liquid crystal device **100** can be viewed on the display screen **302a** of the display unit **302**. In this case, the mobile telephone **300** includes a display control circuit for controlling the liquid crystal device **100**. The display control circuit sends picture signals, other input data, and predetermined control signals to the liquid crystal device **100**, and determines the operations of the liquid crystal device **100**.

It should be noted that the liquid crystal device and the electronic apparatus according to the embodiments of the invention are not limited to the above-described illustrated embodiments, and various modifications can be made without departing from the scope of the invention. For example, while the grooves in the above-described embodiments are square or rectangular in cross section, and the inner bottom portions of the recesses are flat, these shapes are given for convenience of illustration, and the inner bottom portions do not always need to be flat. The cross section of the grooves may have other shapes, for example, a U-shape, a V-shape, or a W-shape.

The entire disclosure of Japanese Patent Application No: 2005-286275, filed Sep. 30, 2005 is expressly incorporated by reference herein.

What is claimed is:

1. A liquid crystal device comprising:
 - a pair of substrates;
 - a liquid crystal layer provided between the substrates; and
 - a plurality of sub-pixels each having a transmissive display region and a reflective display region, wherein one of the substrates includes:
 - switching elements corresponding to the sub-pixels;
 - lines connected to the switching elements; and

an insulating film provided on the switching elements and the lines,

wherein the insulating film includes first recesses provided in the transmissive display regions, and second recesses provided along boundaries between the adjoining sub-pixels,

wherein at least a part of the insulating film other than the first and second recesses planarly overlaps with the reflective display regions,

wherein the thickness of the liquid crystal layer is smaller in the reflective display regions than in the transmissive display regions having the first recesses, and

wherein the depth of the second recesses is smaller than the depth of the first recesses.

2. The liquid crystal device according to claim 1, wherein the sub-pixels are arranged in a horizontal direction and a vertical direction, the first recesses are connected in the horizontal direction, and the second recesses extend along the boundaries between the sub-pixels adjoining in the horizontal direction.

3. The liquid crystal device according to claim 1, wherein the sub-pixels are arranged in a horizontal direction and a vertical direction, the first recesses are connected in the horizontal direction, and the second recesses extend in the vertical direction.

4. The liquid crystal device according to claim 1, wherein the sub-pixels are arranged in a horizontal direction and a vertical direction, each of the second recesses includes a portion extending in the horizontal direction and a portion extending in the vertical direction.

5. A liquid crystal device comprising:

a pair of substrates;

a liquid crystal layer provided between the substrates; and

a plurality of sub-pixels each having a transmissive display region and a reflective display region,

wherein one of the substrates includes:

switching elements corresponding to the sub-pixels;

lines connected to the switching elements; and

an insulating film provided on the switching elements and the lines,

wherein the insulating film includes first recesses provided in the transmissive display regions, and second recesses provided above the lines,

wherein at least a part of the insulating film other than the first and second recesses planarly overlaps with the reflective display regions,

wherein the thickness of the liquid crystal layer is smaller in the reflective display regions than in the transmissive display regions having the first recesses, and

wherein the depth of the second recesses is smaller than the depth of the first recesses.

6. The liquid crystal device according to claim 5, wherein the second recesses are grooves extending along the lines.

7. The liquid crystal device according to claim 5, wherein the sub-pixels are arranged in a horizontal direction and a vertical direction, the first recesses are connected in the horizontal direction, and the second recesses extend in the vertical direction.

8. The liquid crystal device according to claim 5, wherein the sub-pixels are arranged in a horizontal direction and a vertical direction, and the lines extend in the vertical direction, and

wherein the liquid crystal device further includes:

lower lines extending in the horizontal direction below the

lines; and

an interlayer insulating layer provided between the lines and the lower lines.

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9. A liquid crystal device comprising:
 a pair of substrates;
 a liquid crystal layer provided between the substrates; and
 a plurality of sub-pixels each having a transmissive display
 region and a reflective display region,
 wherein one of the substrates includes:
 switching elements corresponding to the sub-pixels;
 lines connected to the switching elements;
 an insulating film provided on the switching elements and
 the lines; and
 a reflecting layer provided on the insulating film in the
 reflective display regions,
 wherein the lines extend along boundaries between the
 adjoining sub-pixels,
 wherein the insulating film includes first recesses provided
 in the transmissive display regions, and second recesses
 provided along the lines,
 wherein at least a part of the insulating film other than the
 first and second recesses planarly overlaps with the
 reflective display regions,
 wherein the thickness of the liquid crystal layer is smaller
 in the reflective display regions than in the transmissive
 display regions having the first recesses, and

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wherein a part of the insulating film in a thickness direction
 is provided between the lines and inner bottom portions
 of the second recesses.

10. The liquid crystal device according to claim 9, wherein
 5 the insulating film includes:

a lower insulating layer provided in the transmissive dis-
 play regions and the reflective display regions; and
 an upper insulating layer provided in the reflective display
 regions, and

10 wherein the lower insulating layer is interposed between
 the lines and the inner bottom portions of the second
 recesses.

11. The liquid crystal device according to claim 1, further
 comprising:

15 pixel electrodes electrically connected to the switching
 elements in the respective sub-pixels; and
 contacts provided between the switching elements and the
 pixel electrodes at edges of inner bottom portions of the
 recesses.

20 12. An electronic apparatus comprising the liquid crystal
 device according to claim 1 as a display unit.

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